

The Structure and Variability of Sagittarius A*: Zooming in to the Supermassive Black Hole at the Galactic Center

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Abstract The Galactic center provides a unique astrophysical laboratory for us to study various astrophysical processes. In this paper, we review and outline the latest results from observations of Sgr A* in terms of source structure and variations in flux density. Sgr A* phenomenon represents a typical case of low radiative efficiency accretion flow surrounding a supermassive black hole in low luminosity AGNs. Many pending astrophysical problems found from observations of Sgr A* have challenged the existing astrophysical theories. Current theoretical models of Sgr A* are also reviewed.

Key words: accretion, accretion disks – black hole physics – galaxies: active – galaxies: nuclei – Galaxy: center – hydrodynamics

1 INTRODUCTION

Sgr A* is an extremely compact and low luminosity source and is believed to be associated with the supermassive black hole at the Galactic center. The nature of its compactness and low radiative luminosity has been puzzling since the discovery of this intriguing radio compact source at the center of the Galaxy (Balick & Brown 1974). Recent observations at the wavelengths from radio to X-ray (*e.g.*, a recent review by Melia & Falcke 2001) have shown growing evidence for its association with a $2.6 \times 10^6 M_{\odot}$ super massive black hole at the dynamic center of the Galaxy (*e.g.*, Ekart & Genzel 1997; Menten *et al.* 1997; Ghez *et al.* 1998; Backer & Sramek 1999; Reid *et al.* 1999). The Sgr A* phenomenon has provided substantial details in understanding the physics associated with a low radiative efficiency accretion flow around a supermassive black hole. In the past decade, numerous models have been proposed for Sgr A* (*e.g.* Melia 1992; Falcke *et al.* 1993; Narayan *et al.* 1998; Yuan *et al.* 2002). An advection-dominated accretion flow (ADAF) suggested by Narayan *et al.* (1998) appears to have successfully provided a dynamical model that can sustain a low radiative efficiency accretion flow around a supermassive black

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hole. However, recent observations at radio and X-ray suggests that the ADAF model appears to be not good enough for Sgr A*. The nature of Sgr A* is still far from clear. In this paper, we will go through the latest results from recent observations in the aspects of spectrum, source structure and time variability in flux densities. Models for Sgr A* are also discussed.

2 RESULTS FROM OBSERVATIONS

2.1 Spectrum

Because of its proximity and uniqueness, Sgr A* is a primary target that has been extensively observed in the past three decades. Fig. 1 shows the well-known spectrum of Sgr A*, indicating that the radiation flux density from this source peaks at ~ 1000 GHz (or 0.3 mm). The radio spectrum seems to be composed of two components, with a break frequency at ~ 50 GHz (e.g., Wright & Backer 1993; Morris & Serabyn 1996; Falcke *et al.* 1998; Falcke 1999). Below this frequency, the spectrum can be characterized by a $\alpha = 0.3$ power-law ($S_\nu \propto \nu^\alpha$), while above the break frequency, the spectrum presents an excess which peaked at 10^{12} Hz. This component has been referred as a sub-millimeter bump (hereafter sub-mm bump). The spectral index of this component appears to be $\alpha > 0.5$ during a flare state and $\alpha \sim 0.25$ in a quiescent state. At higher frequencies above the sub-mm bump, the spectrum drops off steeply as indicated by the infrared observations (Rieke & Lebofsky 1982). Most of the infrared data only give an upper limit in detection (Telesco, Davidson, & Werner 1996; Cotera *et al.* 1999; Genzel & Eckart 1999). Sgr A* may have been detected at $2.2 \mu\text{m}$ in one observation (Genzel *et al.* 1997) but this is the only possible detection to date. The source has not been detected in the optical/UV bands due to the strong extinction (visual extinction of 30 mag.) towards the Galactic center. In general, we believe that the emission from the optical and UV bands is unlikely to exceed the peak at sub-millimeters.

The X-ray spectrum shown in Fig. 1 is derived from the Chandra observations (Baganoff *et al.* 2001, 2002) which is believed to be the first firm detection in X-ray band. The two sets of data show two states, namely quiescent and flare states, denoted by “Q” and “F” respectively. The luminosity and photon index are $L_x = 2.2 \times 10^{33} \text{ erg s}^{-1}$ and $\Gamma \sim 1.5 - 2.7$ for the quiescent state, and $L_x = 10^{35} \text{ erg s}^{-1}$ and $\Gamma \sim 0.7 - 1.8$ for the flare state.

The bolometric luminosity is inferred to be $L \sim 10^{-8.5} L_{\text{Edd}}$ if the mass of the black hole is $M = 2.6 \times 10^6 M_\odot$. Sgr A* is an extremely dim AGN. The spectrum of Sgr A* is quite different from those observed in the luminous AGNs where the luminosity usually peak at optical/UV bands (so-called Big-Blue-Bump). The Sgr A* type of spectrum appears to be common in low luminosity AGNs (LLAGNs; *e.g.* Ho 1999). The difference in the spectra between luminous and low luminous AGNs indicates that a powering mechanism or engine operating in the center of LLAGNs may indeed differ from that in the luminous AGNs. Sgr A* is an excellent case for us to study the astrophysical processes occurring in the centers of low luminosity AGNs.

2.2 Structure

It has been proved difficult in determining the intrinsic structure of Sgr A* because of its compactness and the scattering in the interstellar medium (ISM) at radio wavelengths (*e.g.* Davies, Walsh, & Booth 1976). The scattering of the ISM results in a λ^2 dependence of its diameter as a function of the observed wavelengths.

The apparent images of the source show elongated structure roughly in EW with a constant ratio of 2 between major-to-minor axes (*e.g.* Lo *et al.* 1998). The elongation of the apparent source structure is thought to be due to the anisotropy of the magnetized ISM. Attempts and efforts have been made for a decade in determining the intrinsic structure of Sgr A* using

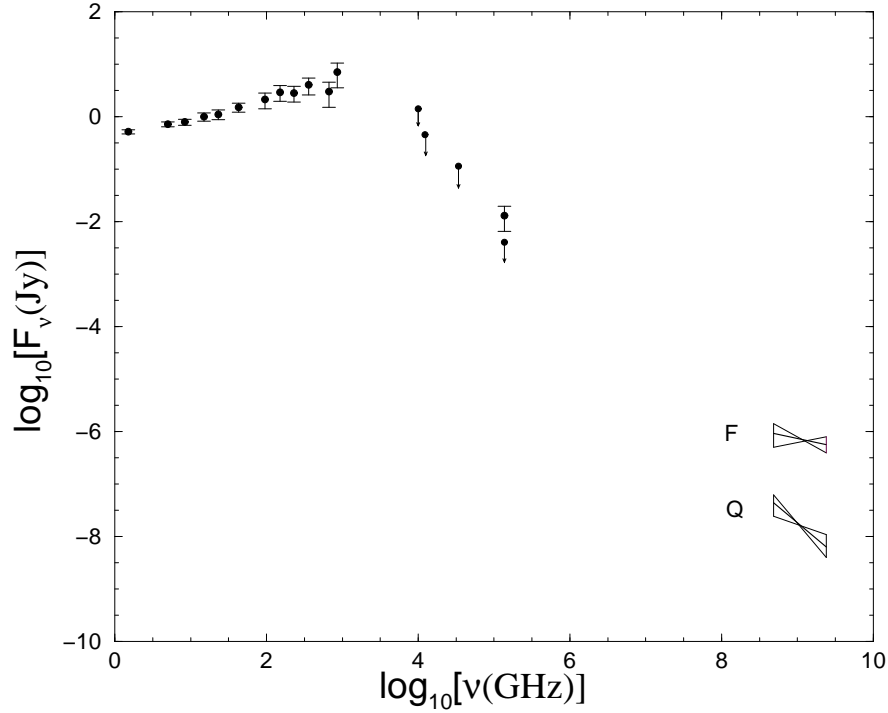


Fig. 1 A spectrum of Sgr A*. The radio and IR data are compiled by Melia & Falcke (2001). The short solid lines in the X-ray error boxes show the best fit to the *Chandra* observation by a power-law model in Baganoff et al. (2001).

VLBI technique at millimeter wavelengths (Backer *et al.* 1993; Krichbaum *et al.* 1993; Rogers *et al.* 1994; Bower & Backer 1998; Lo *et al.* 1998; Doeleman *et al.*, 2001). Fig. 2 illustrates the apparent sizes along both the major and minor axes versus wavelength. The illustration shows that up to the wavelength 7 mm, the apparent image along the major axis is clearly dominated by the scattering. At 7 mm, along the minor axis, a deduced 0.20 ± 0.06 mas deviation from the scattering size may suggest that an intrinsic structure begins to be revealed in NS. At millimeter wavelengths, the scattering effect becomes relatively less severe. The latest results from observations with a VLBI network at 3 mm suggest that the position angle of the major axis tends to differ from the constant value of 80 degree observed at the longer wavelengths. The apparent source structure ($\theta_{maj} = 0.34 \pm 0.14$ mas, $\theta_{min} = 0.17 \pm 0.12$, P.A. = 22 ± 20 deg) derived from an elliptical model fitting to the surface brightness distribution appears to deviate from the scattering structure that is extrapolated from the longer wavelengths with a λ^2 -dependence, indicating the intrinsic extension of the source may be indeed in NS. However, the best-fit circular Gaussian model of FWHM 0.18 ± 0.02 mas to the data suggests that the apparent source structure may be still comparable to the scattering size. The difficulty in determination of the source structure at 3 mm is due to the limited UV coverage in NS and the large atmosphere attenuation which results an uncertainty in calibrating the visibility data. Nevertheless, the intrinsic source size at 3 mm is constrained to be less than 0.27 mas (Doeleman *et al.*, 2001). This new result appears to be consistent with the wavelength dependence of the

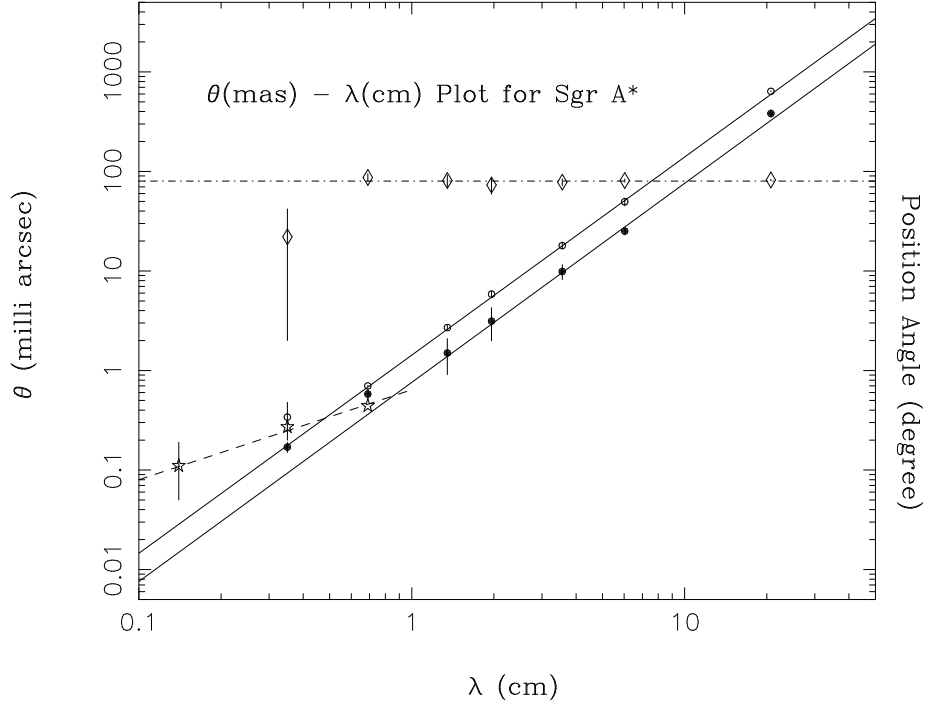


Fig. 2 The source structure of Sgr A*. The measurements at 6, 3.6, 2, 1.3 and 0.7 cm are taken from Lo *et. al* 1998. The measurements at 20 cm is from Yusef-Zadeh *et. al* 1994. The 3 mm measurements use Doeleman *et. al.* 2001. The measurement at 1.4 mm is from Krichbaum *et. al.* 1999. The solid lines are the scattering size fitting to the observed sizes along both the major axis (open circles) and the minor axis (solid dots). The open diamonds indicate the position angle of the apparent elongation. The dashed line is a power law fit to the intrinsic sizes derived from the measurements at 7, 3 and 1.4 mm (open stars).

intrinsic size of Sgr A* as derived from the 7 mm and 1.4 mm measurements:

$$\theta_{int} = 0.08 \lambda_{mm}^{0.9} \text{ mas.}$$

The physical size corresponding to 0.27 mas for a black hole of $2.6 \times 10^6 M_{\odot}$ is about 40 R_s , where $R_s = 7.7 \times 10^{11}$ cm is the Schwarzschild radius assuming the black hole mass to be $2.6 \times 10^6 M_{\odot}$. The radio plasma appears to be highly confined to a small volume around the super massive black hole.

2.3 Flux Density Variation

The variations in radio flux density observed from Sgr A* are established since the discovery of this intriguing radio compact source at the Galactic center in 1974 (Brown & Lo 1982; and Zhao *et al.* 1989). The nature of the radio variability has not been well understood.

Based on observations of flux density variation at 1.3 and 0.8 mm with JCMT, Gwinn *et al.* (1991) found that there were no significant variations in a time scale of 1 sec to a day while they were searching for reflective scintillation.

During the period of 1990-1993, a regular VLA flux density monitoring program was carried out suggesting that the amplitude variation increased towards short wavelengths and that the rate of radio flares appeared to be about three per year (Zhao *et al.* 1992; and Zhao & Goss 1993). The typical time scale of these radio flares is about a month. Large-amplitude fluctuations in the flux density observed at 3mm (Wright & Backer 1993; Tsuboi, Miyazaki and Tsutsumi 1999) appeared to be consistent with what were observed at centimeter wavelengths. Based on the radio-monitoring data obtained with the 3.5 km Green Bank Interferometer (GBI) at 11 and 3.6 cm, a characteristic time scale of 50-200 days was observed at both wavelengths and the structure function of 11 cm data suggested a quasi-periodic variation with a period of 57 days (Falcke 1999).

A presence of a 106 day cycle in the radio variability of Sgr A* was revealed based on an analysis of data observed with the VLA over two decades (Zhao, Bower and Goss 2001). The results derived from VLA archived data show that the pulsed components with a spectral index of 1.0 ± 0.1 and an amplitude $\Delta S = 0.42 \pm 0.04$ Jy and a characteristic timescale of $\Delta t_{FWHM} \approx 25 \pm 5$ days. The lack of a VLBI detection of secondary component suggests that the variability arises from Sgr A* on a scale of ~ 5 AU.

A new regular VLA monitoring program at wavelengths 2, 1.3 and 0.7 cm with a typical sampling interval of a week has been launched since the mid of year 2000. The preliminary results based on the data obtained in the past 500 days show that the fluctuation in flux density appears to persist (McGary *et al.* 2002; Bower *et al.* 2002). The power spectral density (psd) profiles show that the cycle lengths of the pulsed signals are 133 ± 3 , 135 ± 3 and 121 ± 3 days for observing wavelengths of 2, 1.3 and 0.7 cm, respectively. The length of the cycle time appears to become longer as compared to the 106 day cycle derived from the VLA archive data in the period between 1977 to 1999. In addition, the lags derived from the light curves suggest that short wavelengths tend to peak first.

A short millimeter and sub-millimeter monitoring program has also been carried out with the Sub-millimeter Array (SMA) of Smithsonian Astrophysical Observatory since mid March of 2001 (Zhao *et al.* 2002). A total of 19 epochs of observations were made at 1.3 and 0.87 mm. The SMA light curve of Sgr A* at 1.3 mm suggests that two flares from Sgr A*. The March flare (started from 4.1 ± 0.5 Jy after an unseen peak and decreased to 1.1 ± 0.15 in three months) appeared to be relatively stronger than that in July (3.1 ± 0.3 Jy). The two flares show a good correlation between the 1 mm flux densities and those measured with VLA at 1 to 2 cm. Considering the fact that the peak was not seen, there might be a time-delay between 1mm and 1 cm during the March event. During the second event, the VLA light curves show a slow increase in flux density suggesting a significant delay. In addition, the spectral index varied from 0.5 ± 0.1 of the March flare to 0.23 ± 0.07 in the June minimum and then increased to 0.6 ± 0.1 in the July flare. The steep rising spectra of Sgr A* during the flares do show an excess of short-mm/sub-mm but this sub-mm bump does not appear to be a stable component. In addition, time separation between the two flares (March and July) is ≥ 120 days, which is consistent with the cycle length derived from PSD analysis of the new VLA data. We note that the observations at 1.3mm were poorly sampled but the weekly VLA observations show there were no additional significant flares between the March and July events.

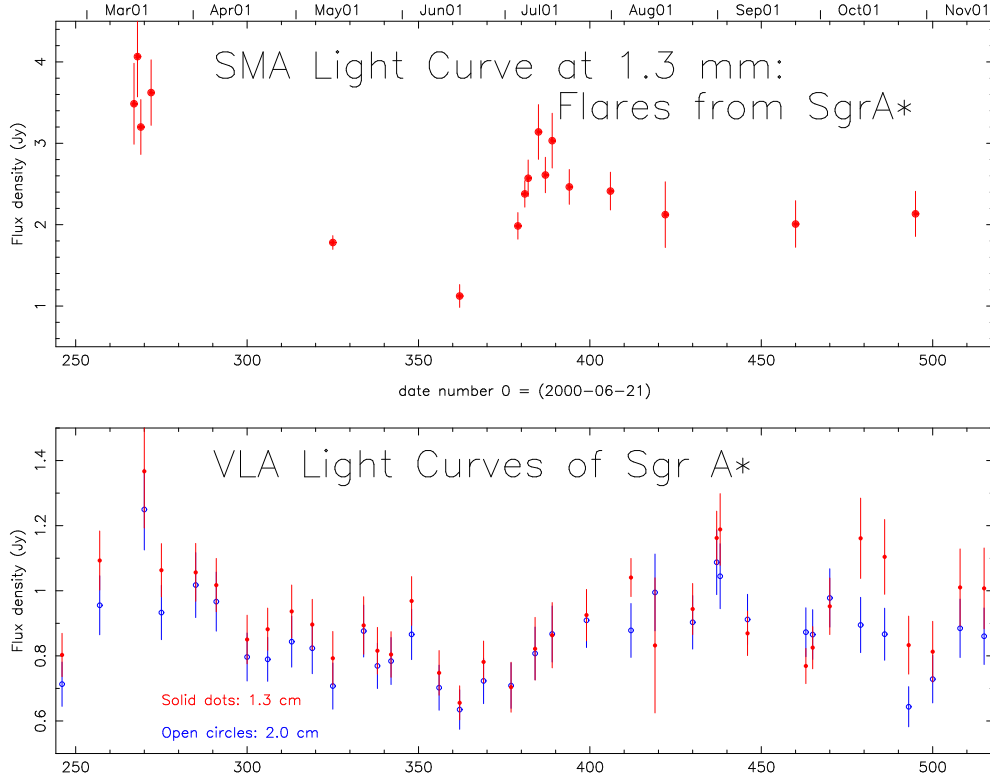


Fig. 3 The light curve of Sgr A* observed at 1.3 mm with the SMA of Smithsonian Astrophysical Observatory (upper panel) is compared with the radio light curves (lower panel) observed at 1.3 and 2 cm using the VLA of NRAO in the period between March to November year 2001 (Zhao *et al.* 2002; McGary *et al.* 2002). The preliminary results of the 1.3 mm observations with the partially completed SMA were reported in the 199 AAS meeting in Washington D.C. (Young *et al.* 2002 and Zhao *et al.* 2002).

An independent monitoring program at 3 mm was carried out with Nobeyama Millimeter Array (NMA) since 1996 and several flares were observed in the period of 1996 to 2001 (Tsuboi, Miyazaki and Tsutsumi 1999; Miyazaki, Tsutsumi and Tsuboi 2001). Due to the fact that Sgr A* monitoring observations require long baselines or large array configurations in order to separate the point source of Sgr A* from the surrounding extended HII emission, the monitoring observations with NMA were only available in a period from late fall to early spring each year. The NMA light curve produced from the nearly 60 measurements at 90 and 102 GHz shows several flares during the course of monitoring. There are several gaps in the NMA sampling. A profile produced by folding the 3mm data into a 106 day module also shows two distinguishable phases: one with flares and another representing quiescent states (Tsuboi *et al.* 2002, private communication). It will be interesting to see how the absolute phase at 3 mm is related to the phases of the flux density fluctuation observed at other wavelengths.

Finally, the flare of Sgr A* observed with Chandra in the X-ray on 27 October 2000 (Baganoff *et al.* 2001) appeared to be followed by radio peaks about a week later at all three

VLA wavelengths (2, 1.3 and 0.7 cm; McGary *et al.* 2002). The X-ray flare is strong (a factor of 50 increase) and short (timescale of 1 hr) and the radio event is relatively weak ($\sim 30\%$ increase) and long (timescale of a few weeks). The correlation between the X-ray and radio flares are consistent with a picture that the X-ray flares may be related to mass ejection originating from active regions in the inner part of the accretion disk. The high-energy electrons accelerated through a process such as shock or magnetic reconnection in the active region are transported to the outer region via a bulk motion of an outflow (or a jet). At a certain distance from the super massive black hole, the outflow tends to be disrupted. The high-energy particles along with the disrupted outflow lose their outwards bulk momenta and are then recycled back to the disk. Assembling these processes may produce a variation cycle in flux density if an MHD convection is dominant in the dynamics of the accretion fluid. The observed quasi-periodic cycle in flux density fluctuation may have provided evidence for that a convection driven by an MHD dynamo may indeed operate in the accretion disk at Galactic center. The discussion here provides a qualitative scenario in understanding the observations. How to cope with the observed variability is still a challenging problem to the current astrophysical theories in modeling the low radiative efficiency accretion flow (*e. g.*, Igumenshchev & Narayan 2002; Narayan 2002).

3 THEORETICAL MODELS

Almost all models proposed for Sgr A* are based on accretion onto the central massive black hole. In general, there are three types of models for Sgr A*, namely accretion, non-accretion flow (such as jet or outflow wind) and their combination. The accretion rate derived from the Chandra observations (Baganoff *et al.* 2002) is about $10^{-4} \dot{M}_{Edd}$, where \dot{M}_{Edd} is the Eddington accretion rate. This rate would result an unreasonably high luminosity if the radiative efficiency is assumed to be the canonical value of a standard thin disk ($\eta \sim 0.1$). Then, all the models must confront with the low radiative efficiency problem.

3.1 Accretion Flow Models

The first accretion model proposed is spherical accretion model (Melia 1992; 1994; Melia, Liu, & Coker 2001). In the latest version of this model, considering that the specific angular momentum of accretion flow is likely very low, the accretion flow is assumed to be free-fall until a Keplerian disk is formed within a small “circularization” radius, $r \sim 5 - 10R_s$. The electrons in the small Keplerian disk can attain a very high temperature through some magnetic heating processes, $T_e \gtrsim 10^{11} \text{K}$, a significant mass loss is assumed so that the density of the particles is extremely low, $n \sim 10^{6-7} \text{electrons cm}^{-3}$, and the magnetic field is about 10-20G. Thus the low efficiency is achieved due to the mass loss in this model. The synchrotron and self-Compton emission from the small Keplerian disk can be utilized to explain the observed sub-mm bump and the X-ray spectrum, respectively.

A transition from a spherical flow to a small disk is interesting but the formation of the small Keplerian disk may not be a necessary result of low angular momentum accretion. An accretion flow with very low angular momentum can still be described by a “disk”, although such accretion may belong to the different modes (Bondi-like type or disk-like type), as shown by Yuan (1999) (see also Abramowicz & Zurek 1981; Abramowicz 1998). Considering their spectral prediction, this model can’t fit the low-frequency radio spectrum below the sub-mm bump. In fact, as shown by Liu & Melia (2001), the thermal synchrotron emission from an accretion flow is unlikely to fit the low-frequency radio spectrum. In the X-ray band, this model suggests that almost all the flux arises from an extremely compact region via the inverse Compton scattering of synchrotron emission. However, the Chandra X-ray observation suggests that the source is extended in its quiescent state (Baganoff *et al.* 2002).

Another accretion flow model for Sgr A* is ADAF (Narayan et al. 1995; Manmoto et al. 1997; Narayan et al. 1998). The most attractive feature of the ADAF model is its ability to explain the unusual low-luminosity of Sgr A* given the relatively abundant accretion material. The basic assumption in this model is that the viscous dissipation prefers to heating ions only and the Coulomb collision is the only coupling mechanism between ions and electrons. Consequently, the dissipation energy due to the viscosity is stored in the ions and advected into the black hole rather than radiated away (Ichimaru 1977; Rees et al. 1982; Narayan & Yi 1994, 1995; Abramowicz et al. 1995). In the innermost region of ADAF the particle density is about 10^{8-9} cm^{-3} , $T_e \sim 10^{10} \text{ K}$, which is quite different from those used in the small disk (Melia *et al.* 2001).

In the application of ADAF to Sgr A*, the radio spectrum is produced by the thermal synchrotron emission in the innermost region of the disk. The X-rays are mainly due to bremsstrahlung radiation of the thermal electrons in a large range of radii $\sim 10^4 - 10^5 R_s$, which is in an excellent agreement with the observed extension of the source. However, the observed radio flux density appears to be a problem to the ADAF. By fitting a spectrum produced from ADAF to both the X-ray flux density in the Q state and the sub-millimeter peak, the radio flux density derived from ADAF alone is an order of magnitude below the radio flux density of Sgr A* observed at centimeter wavelengths.

In the X-ray band, the spectrum predicted by a canonical ADAF model, in which most of the dissipation energy is used to heat ions mainly, is somewhat too hard (but see Quataert 2002 for an explanation). In addition, the canonical ADAF model appears to be difficult in explaining the possible rapid fluctuation detected in the Q state by Baganoff et al. (2002) (Yuan, Markoff, & Falcke 2002). However, the two problems can be solved if the electrons are heated directly by a moderately large fraction of the viscous dissipation energy. In such a case, the second order Comptonization of the synchrotron emission will contribute significantly to the X-ray spectrum (see Figure 4. of Narayan 2002). Taking into account strong winds from ADAF can't make the fitting better if the wind is assumed not to radiate (Yuan, Markoff, & Falcke 2002). Thus a second component with a soft spectrum and a rapidly variable nature may be needed to explain the observed X-ray emission.

There are other low radiative efficiency accretion models which can potentially explain the observations of Sgr A* such as convection-dominated accretion flows (CDAFs). Recent 3-D MHD simulations of spherical accretion conducted by Igumenshchev and Narayan (2002) suggests that the MHD accretion flow will eventually transit to a state of self-sustained convection via the MHD buoyancy-induced motions, magnetic field reconnection and gas heating. An MHD CDAF coupling with relevant high energy particle cooling mechanism will be interesting in understanding the Sgr A* phenomenon. A recent review by Narayan (2002) covers the theoretical front of the CDAF in details.

3.2 Jet Model

In the second kind of model for Sgr A*, it is assumed that the accretion flow contribute little to the total luminosity of Sgr A* and the flux comes from a jet/outflow (Reynolds & McKee 1980; Falcke, Mannheim, & Biermann 1993; Falcke & Biermann 1999; Falcke & Markoff 2000). This is based on the idea of Blandford & Königl (1979) that flat-spectrum radio cores are best explained by synchrotron-emitting jets. In the most updated version of jet model for Sgr A*, the sub-mm bump is due to the synchrotron emission from the acceleration region in the base of the jet, called nozzle. The parameters describing the nozzle is $n \sim 10^{6-7} \text{ cm}^{-3}$, $T_e \sim 10^{11} \text{ K}$, and $B \sim 20 \text{ G}$. The parameters used here are similar to those in the models proposed by Beckert & Duschel (1997) and Melia, Liu, & Coker (2001).

Following the evolution of the plasma in the nozzle described by the above parameters on its way out using the Euler equation, the emission from the jet can well interpret the low-frequency radio emission of Sgr A*. As mentioned above, the radio spectrum is difficult to be explained by the either Bondi-accretion flow or ADAF. In addition, the inverse Compton emission of the plasma in the nozzle can explain the soft X-ray spectrum and its possible rapid variability.

But the remaining important problem in the jet model is why the parameters of the jet possess the required values, particularly in reference to the inferred underlying accretion disk. Previous ideas of a standard optically thick accretion disk for Sgr A* do not seem to work because the predicted IR flux from a standard thin disk with a reasonable accretion rate would be several orders of magnitude higher than the observed IR upper limit (Falcke & Melia 1997). In addition, the jet model can't explain why an extended X-ray source is observed since the radius and height of the nozzle is only $\sim 4GM/c^2$, $10GM/c^2$, respectively.

3.3 Jet-ADAF model

The observations to Sgr A* strongly suggest that a jet and an ADAF may co-exist in the immediate environment surrounding the super massive black hole at the Galactic center. The emission of Sgr A* might be indeed produced from both the jet and the ADAF. On one hand, the flat radio spectrum is best explained by the jet emission, and the possible rapid variability at the X-ray band and the soft X-ray spectrum also suggest that the inverse Compton emission from the jet nozzle should contribute partly. On the other hand, the observed extended feature of the source strongly indicates the existence of the bremsstrahlung emission from ADAF. Therefore, it is crucial to consider the jet and accretion flow as a coupled system in Sgr A*. We need also to consider what are their respective roles if both are truly present in Sgr A*.

Yuan, Markoff & Falcke (2002) propose a coupled jet-ADAF model to describe the emission of Sgr A*. This model can also provide a convincing explanation to the spectrum during the X-ray flare state of Sgr A* (*e.g.* Markoff et al. 2001). This is a good advantage using the jet-ADAF coupling model in explaining observed spectrum and variability as compared to the models using accretion flow alone. Within $r \sim 4GM/c^2$, a fraction of the accretion plasma is ejected out of the ADAF and forms the jet. A standing shock occurs in this process since the accretion flow is radially supersonic at $r \sim 4GM/c^2$. From the shock transition condition, we can determine the post-shock temperature. But the post-shock density depends on what a fraction of the accretion flow will be transferred into the jet which is related to the jet-formation physics and is hard to determine due to the fact the jet-formation process is still poorly understood. We use parameters to describe such a process. As usual, the magnetic field is determined by a parameter describing the ratio between the magnetic energy to the post-shock thermal energy. Once the parameters describing the nozzle are determined, the emission from the nozzle and jet can be calculated. The resulting spectrum from Sgr A* is the sum of the jet and ADAF. The X-ray emission is partly due to the bremsstrahlung emission from the ADAF and partly due to the inverse Compton from the nozzle, thus the source is extended and the rapid variability can be explained. The low-frequency radio spectrum is almost completely dominated by the emission from the jet while the sub-mm bump is the sum of the emissions from the jet and ADAF.

Although the jet-ADAF model seems to be able to explain the spectrum of Sgr A* ranging from radio to X-ray very well, a lot of work still need to be done. The most important part of the uncompleted work is to fill in the details for the coupling between the jet and disk. We are still not certain how the accretion flow is ejected out of the disk and how jet material is accelerated via the nozzle.

4 SUMMARY

In this paper we review the observations of Sgr A* in the aspects of its structure and variation in flux density and outline the current theoretical models of this source. Most of these models focus only on the fitting to the observed spectrum. The structure of Sgr A* is discussed in the jet model by Falcke & Markoff (2000). However, based on the VLBI observations, the reality is that down to an angular scale of 0.27 mas (~ 40 Schwarzschild radii) there is still no convincing evidence for intrinsic extended structure. The variation in flux density at 1cm to 1mm shows that a flux density varies by 50% at 1 cm and by a factor of 3 at 1 mm in a typical time scale of 1 month. The variation in flux density between a flare state and a quiescent state suggests a fluctuation cycle of four months. If the the variation in flux density is related to a jet or outflow, a fluctuation in intrinsic source size around 0.2 mas is expected at the short wavelengths. Due to the strong ISM scattering at long wavelengths and availability in the millimeter VLBI technique, the best observing wavelength is at 3 mm.

Monitoring the flux density at multi-wavelengths between centimeter, millimeters, sub-millimeter, IR and X-ray is necessary in order to understanding the radiative cooling in the high energy processes occurring in this source.

The fluctuation cycle observed at the wavelengths between short centimeters to short millimeters is interesting but has not been well understood yet. Understanding the fluctuation cycle may naturally lead us to understanding the dynamical link between the accretion inflow and jet outflow that may co-exist in Sgr A*. In other words, the variability will put a strong constraint on the theoretical models of Sgr A*.

Moreover, our understanding to Sgr A* phenomena will help us in understanding the puzzling nature of LLAGNs.

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